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Coupling interaction between biodiversity and aquatic habitat area in Western Route Project vicinity

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Abstract: The Western Route of the South-to-North Water Transfer Project will divert water from the upper Yangtze River and its tributaries, the Dadu River and Yalong River, to the upper Yellow River. The project may ease the water shortage in the Yellow River Basin. However, it may also have some effects on the ecosystem in the upper Yangtze River Basin. Benthic invertebrates play an important role in the river ecosystem, particularly in the circulation of materials and nutrition. Benthic invertebrates are widely used to quickly assess river ecosystems because of their rapid response to changes in the water environment. The diversity of benthic invertebrates is closely associated with the aquatic habitat area. This study examined this interaction by sampling the benthic invertebrates in an expanding area. The conclusions are that the diversity of benthic invertebrates begins to decrease when the aquatic habitat area is reduced to 45% of the original area, and decreases dramatically when the aquatic habitat area is reduced to 10% of the original area. The aquatic habitat area should be kept at more than 45% of the original area in order to maintain the significant diversity of benthic invertebrates.
Key words: *Western Route Project; South-to-North Water Transfer Project; river ecosystem; benthic invertebrates; biodiversity; aquatic habitat area*

1 Introduction

The South-to-North Water Transfer Project consists of the East Route Project, Middle Route Project, and Western Route Project. The Western Route Project will divert water from the Dadu River and Yalong River. In the Dadu River Basin, four dams will be built and 23.5×10^8 m^3 of water will be diverted. In the Yalong River Basin, three dams will be built and 56.5×10^8 m^3 of water will be diverted. The project will ease the water shortage in Northwest China significantly. At the same time, it will reduce runoff downstream of the dams and may have adverse effects on the river ecosystem.

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Benthic invertebrates are basic and important components of the river ecosystem and usually show a high level of biodiversity in a given location (Wallace et al. 1996). They play an important role in the aquatic ecosystem. In terrestrial ecosystems, microorganisms break down materials, but in aquatic ecosystems this work is carried out by benthic invertebrates. Benthic invertebrates are the consumers and carriers of energy and materials. They influence the aquatic ecosystem directly or indirectly by food intake and burrowing. For example, they can accelerate the decomposition of benthic scrap and promote the self-purification of the water body (Chen 2003). Benthic invertebrates lie in the middle of the food chain, and they can consume the pollution in the river and supply food for other creatures simultaneously. Some research suggests that most wetland birds live on benthic invertebrates and therefore their spatial distribution is determined by benthic invertebrate distribution (Masero et al. 1999; Atkinson et al. 2000). Beyond that, benthic invertebrates are sensitive to water quality and are often used to quickly assess river ecology (Lu 2003; Yeom and Adams 2007). They respond rapidly to changes in the water environment. When there are changes in water quality, benthic invertebrates may respond instantly; their species diversity and distribution will change. In China, benthic invertebrates have been used for water monitoring since the early 1970s (Yang and Tian 1994). Sampling results indicate that the biodiversity of benthic invertebrates is coincident with the river ecology. If the benthic biodiversity is high, the river ecology is fine. If the river channel is unstable or the water is polluted, the benthic biodiversity is low. In rivers whose water is transferred elsewhere, benthic invertebrates are the first to be affected when the runoff reduction occurs. This study focused on the effects of the water transfer project on benthic invertebrates.

There are many factors affecting the total species and numbers of benthic invertebrates, including the substrate, the flow rate, and the water depth (Reinhold-Dudok and den Besten 1999; Reice 1985; Arunachalam et al. 1991; Beisel et al. 1998; Verdonschot 2001). Some research indicates that the particle size, porosity, and interstitial dimension of the substrate have significant effects on benthic invertebrates. Experiments have been carried out in the field with five kinds of substrate: fine sand, coarse sand, gravel, cobble, and stone. The biodiversity is highest when the substrate is composed of gravels and lowest when the substrate is composed of fine sand. The species type is more stable when the substrate is composed of cobble or stone. The composition and diversity of benthic invertebrates are also affected by the porosity and the interstitial dimension of the substrate. The higher the habitat heterogeneity of the substrate is, the greater the biodiversity (Duan et al. 2007).

There is a close connection between the substrate, flow rate, water depth, and aquatic habitat area. In general, if the aquatic habitat area is large enough, it will contain various substrates, flow rates, and water depths; that is, the habitat heterogeneity is high. Thus, the diversity of benthic invertebrates depends on the aquatic habitat area to some extent. This study focused on the relation of the diversity of benthic invertebrates to the aquatic habitat area in the vicinity of the Western Route Project. The minimum aquatic habitat area necessary for the benthic invertebrates to survive was obtained.

2 Sampling and species identification

2.1 Sampling

The benthic invertebrates were sampled in Ganzi, Sichuan Province, in the upper reach of the Yalong River, where the industry is underdeveloped and where there is little river pollution. As shown in Fig. 1, the selected 15-km reach contains diverse habitats, including straight river courses, river bends, and wetlands, and the substrates include gravel, cobble, and silt. Therefore, the biodiversity is high. This means that the results are accurate and credible.

(a) Substrates composed of cobbles and silt

(b) Different flow velocities

Fig. 1 Different substrates and flow velocities in sampling reach

The first sample site was in a straight river course. The initial four sampling areas were 0.1 m^2, 0.5 m^2, 1 m^2, and 2 m^2. The sampling range was expanded step by step to cover all kinds of habitats, including straight channels, river bends, and wetlands linked or unlinked to the river. Each individual sampling area was 1 m^2. All the sample sites contained various substrates, flow rates, and water depths. The area of the habitats near a sample site with the similar characteristics was regarded as the representative area of the sample site and added in the total area. The total sampling area can be calculated with the following expression:

$$A = \sum_{i=1}^{n} A_i \tag{1}$$

where n is the number of the sample site, A is the total sampling area, and A_i is the representative area of the ith sample site.

If the area of the habitats near a sample site with the similar characteristics is large, the representative area of the sample site is large as well. The maximum representative area can reach 1 000 m^2 and the minimum only 20 m^2. The total sampling area was 7 854 m^2. The number of species of benthic invertebrates increases with the sampling area, as shown in Table 1. There are many different species in the straight river courses and the river bends, but few in the isolated wetlands. The biodiversity is high in the gravel and cobble riverbeds, and low in the silt riverbed.

Table 1 Number of benthic invertebrate species with different sampling areas

Ratio of aquatic habitat area to total sampling area (%)	Number of benthic invertebrate species in *i*th sample site	Number of new benthic invertebrate species	Total number of benthic invertebrate species	Ratio of aquatic habitat area to total sampling area (%)	Number of benthic invertebrate species in *i*th sample site	Number of new benthic invertebrate species	Total number of benthic invertebrate species
0.006	9		9	9	14	1	34
0.013	17	10	19	16	10	1	35
0.025	9	3	22	25	12	1	36
0.314	14	3	25	31.36	4	1	37
0.922	16	3	28	43.56	4	1	38
1.85	15	2	30	64	6	0	38
3.10	14	2	32	81	5	0	38
4.67	12	1	33	100	6	0	38

2.2 Species identification

The identification results indicate that there are 38 species in all, belonging to 10 orders and 31 families, as shown in Table 2. Most of them were identified by family, and some were distinguished by genus.

Table 2 Species identification results

Order	Family	Species	Number of benthic invertebrate	Order	Family	Species	Number of benthic invertebrate
Amphipoda	Gammaridae		318	Trichoptera	Ecnomidae		2
Acariformes	Undetermined		17		Brachycentridae		92
Ephemeridae	Baetidae	Sp.1	33		Limnephilidae		1
		Sp.2	25		Hydroptilidae		5
		Sp.3	4		Rhyacophilidae		1
	Heptageniidae				Sericostomatidae		3
	Potamanthidae				Hydropsychidae		22
	Ephemerellidae				Polycentropodidae		1
	Undetermined				Leptoceridae		1
Diptera	Chironomidae	Sp.1	149		Xiphocentronid		5
		Sp.2	57		Stenopsychidae		1
		Sp.3	13		Phryganeidae		1
	Simulidae		9		Undetermined		2
	Tipulidae	Sp.1	182	Plecoptera	Perlidae	Sp.1	15
		Sp.2	40			Sp.2	1
		Sp.3	1		Chloroperlidae		3
	Empididae		1	Oligochaeta	Tubificidae		48
Coleoptera	Elmidae		4	Turbellaria	Undetermined		1
	Hydraenidae		1	Gastropoda	Lymnaeidae		3

3 Biodiversity and aquatic habitat area

Fig. 2 can be drawn according to Table 1. The curve is steep at first and the number of benthic invertebrate species increases quickly with the expansion of the aquatic habitat area. When the aquatic habitat area expands to a certain range, the curve flattens and the number of species levels off. The number of benthic invertebrate species shows no significant difference when the aquatic habitat area is reduced to 45% of the original area, but if the area is further reduced, the number of benthic invertebrate species begins to decrease. When the area decreases to 10% of the original area, the number of benthic invertebrate species decreases slowly, from 38 to 33; if the area decreases further, the number of benthic invertebrate species will decrease sharply. Thus, 45% and 10% are the critical values for the aquatic habitat area. If the aquatic habitat area is reduced to a critical value, some measures should be taken to maintain the stability of the number of benthic invertebrate species.

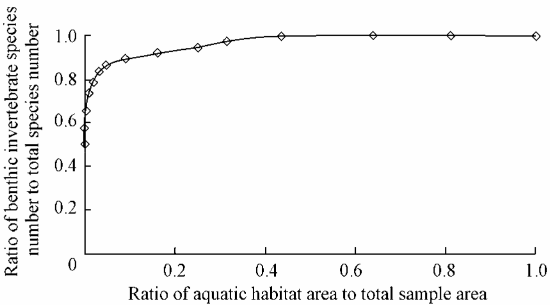

Fig. 2 Relation of number of benthic invertebrate species to aquatic habitat area

The aquatic habitat area is closely connected with habitat heterogeneity. The bigger the aquatic habitat area is, the greater the habitat heterogeneity, and the greater the diversity of benthic invertebrates. The diversity of the substrate, flow rate, and water depth decreases with the reduction of the aquatic habitat area, so the habitat heterogeneity decreases too, as does the diversity of the benthic invertebrates.

With logarithmic coordinates, Fig. 2 can be redrawn as Fig. 3. If the experiment results are applied to other regions, the following expression is obtained:

$$R = \begin{cases} 1.066W^{0.08} & W < 0.45 \\ 1 & W \geq 0.45 \end{cases} \tag{2}$$

where R is the ratio of the rest of the species to the total species of benthic invertebrates, and W is the ratio of the rest of the area to the original area of the aquatic habitats. The diversity of benthic invertebrates can be predicted when the aquatic habitat area has changed in accordance with Eq. (2).

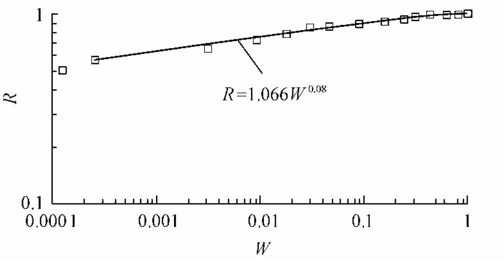

Fig. 3 Relation of R to W (shown with logarithmic coordinates)

4 Impacts of water diversion on benthic invertebrates

The operation of the Western Route Project will reduce runoff in the Dadu River and Yalong River, especially downstream of the dams. The aquatic habitat area will decrease. The frequency of flooding will be reduced and the wetlands connected with the river will be cut off. The exchange of materials and nutrients between the river and the wetlands will be blocked, which will harm the river ecology and may cause the biodiversity of benthic invertebrates to decrease (Wang et al. 2007).

On the basis of Eq. (2) and the stage-discharge relation, the decrease of the aquatic habitat area can be estimated and the biodiversity of benthic invertebrates can be calculated. The condition of the river ecology can be evaluated, providing a basis for the operation of the water diversion projects.

5 Conclusions

Benthic invertebrates play an important role in the river ecosystem and are usually used to quickly assess the river ecology. Their biodiversity depends on the habitat heterogeneity, which is closely connected with the aquatic habitat area. Thus, the diversity of the benthic invertebrates has a close relation with the aquatic habitat area. The number of species of benthic invertebrates increases with the expansion of the aquatic habitat area and then levels off.

When the aquatic habitat area is reduced to 45% of the original area, the number of species of benthic invertebrates begins to decrease; it then drops dramatically when the aquatic habitat area is reduced to 10% of the original area. Thus, 45% and 10% are the critical values for the aquatic habitat area in terms of maintenance of the stability of the number of benthic invertebrate species.

The water diversion project will reduce the runoff in the Dadu River and Yalong River. As a result, the number of benthic invertebrate species will decrease. Eq. (2) can be used to estimate the number of benthic invertebrate species, which in turn can be used to evaluate the condition of the river ecology. To maintain a high diversity of benthic invertebrates and a good river ecosystem, the reduction of the aquatic habitat area induced by the water diversion project should be less than 55% of the original aquatic area.

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